Electromagnetic, Thermal and Structural Analysis of the LUX Photoinjector Cavity using ANSYS

Steve Virostek

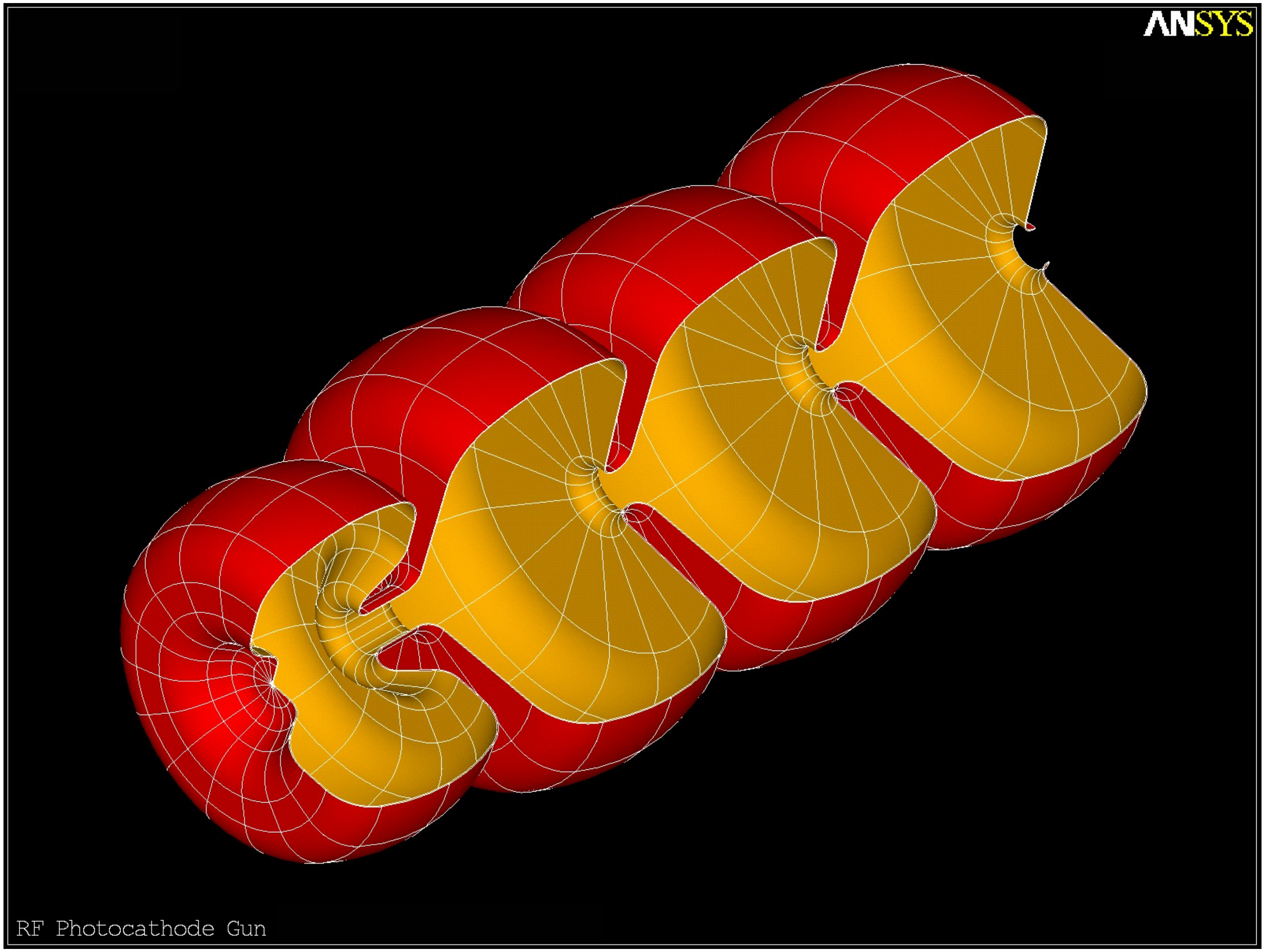
Lawrence Berkeley National Lab

13 December 2004

Photoinjector Background

- The proposed LBNL LUX project is a linac/laser based, femtosecond-regime X-ray facility
- The photoinjector is a room-temperature 1.3 GHz 4 cell structure producing a 10 MeV, nominal 30 psec, 1 nanocoulomb electron bunch at a 10 kHz rate
- The first cell is of reentrant geometry, with a peak field of 64 MV/m at the photocathode surface
- The high repetition rate and high peak power results in a high average surface power density
- The RF system will be designed to provide a short, high-power driving pulse and active removal of stored energy after the beam pulse to reduce the average power dissipated in the cavity

Photoinjector Vacuum Wall



Relevant Publications

- J.W. Staples, S.P. Virostek and S.M. Lidia, "Engineering Design of the LUX Photoinjector", EPAC 2004

  Description of the configuration and operating parameters of Cell 1 of the LUX photoinjector. Details and results of the RF, thermal and structural modeling of the cavity are provided including a discussion of cavity frequency shift due to loading conditions.

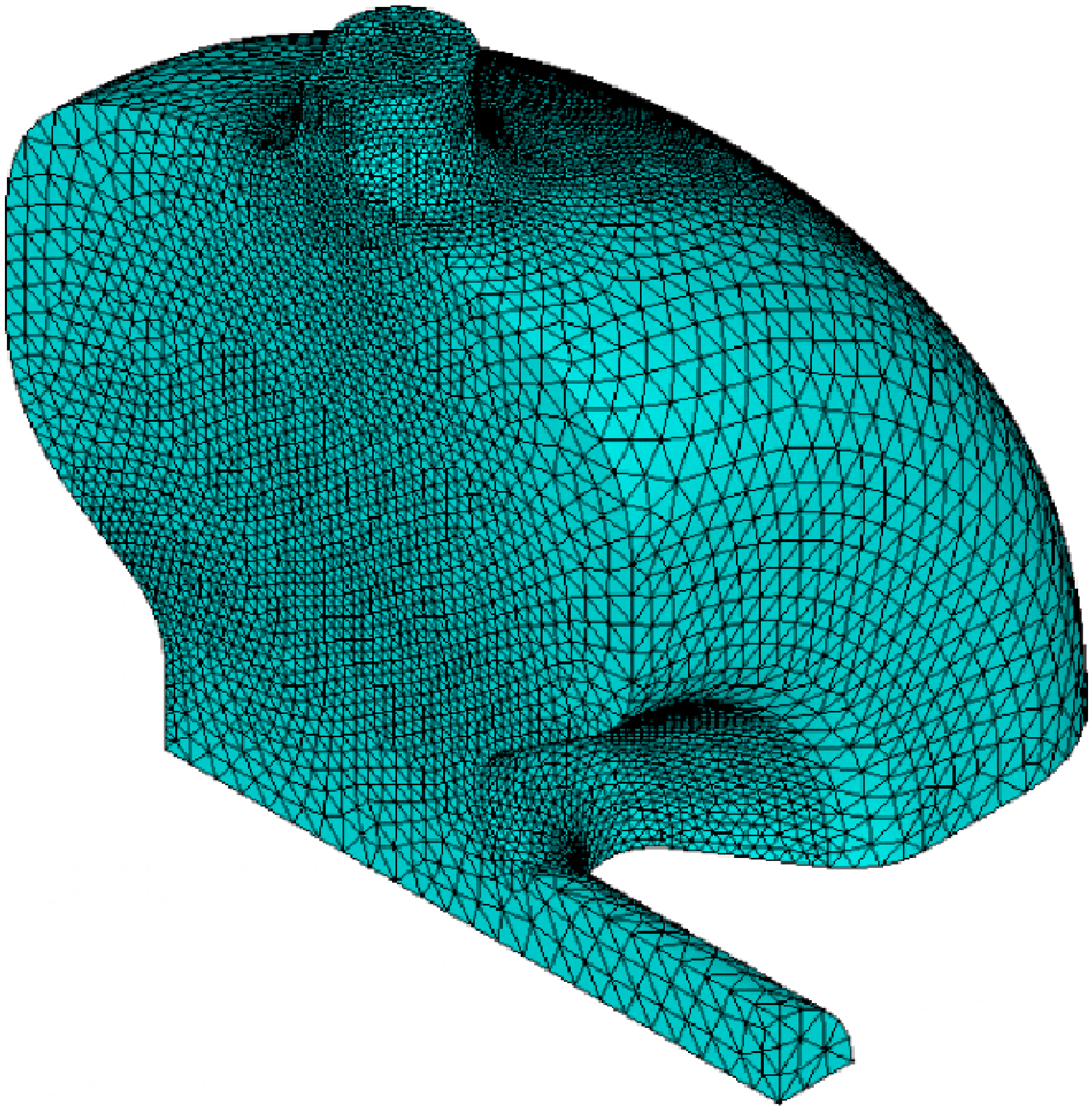
- N. Hartman and R.A. Rimmer, "Electromagnetic, Thermal, and Structural Analysis of RF Cavities using ANSYS", PAC 2001

  Report on technique for combined cavity analysis. Methods for importing CAD solid models and creating an acceptable mesh are discussed. A mesh sensitivity study is presented as well. The modeling method is applied to a proposed cavity for the NLC damping rings.

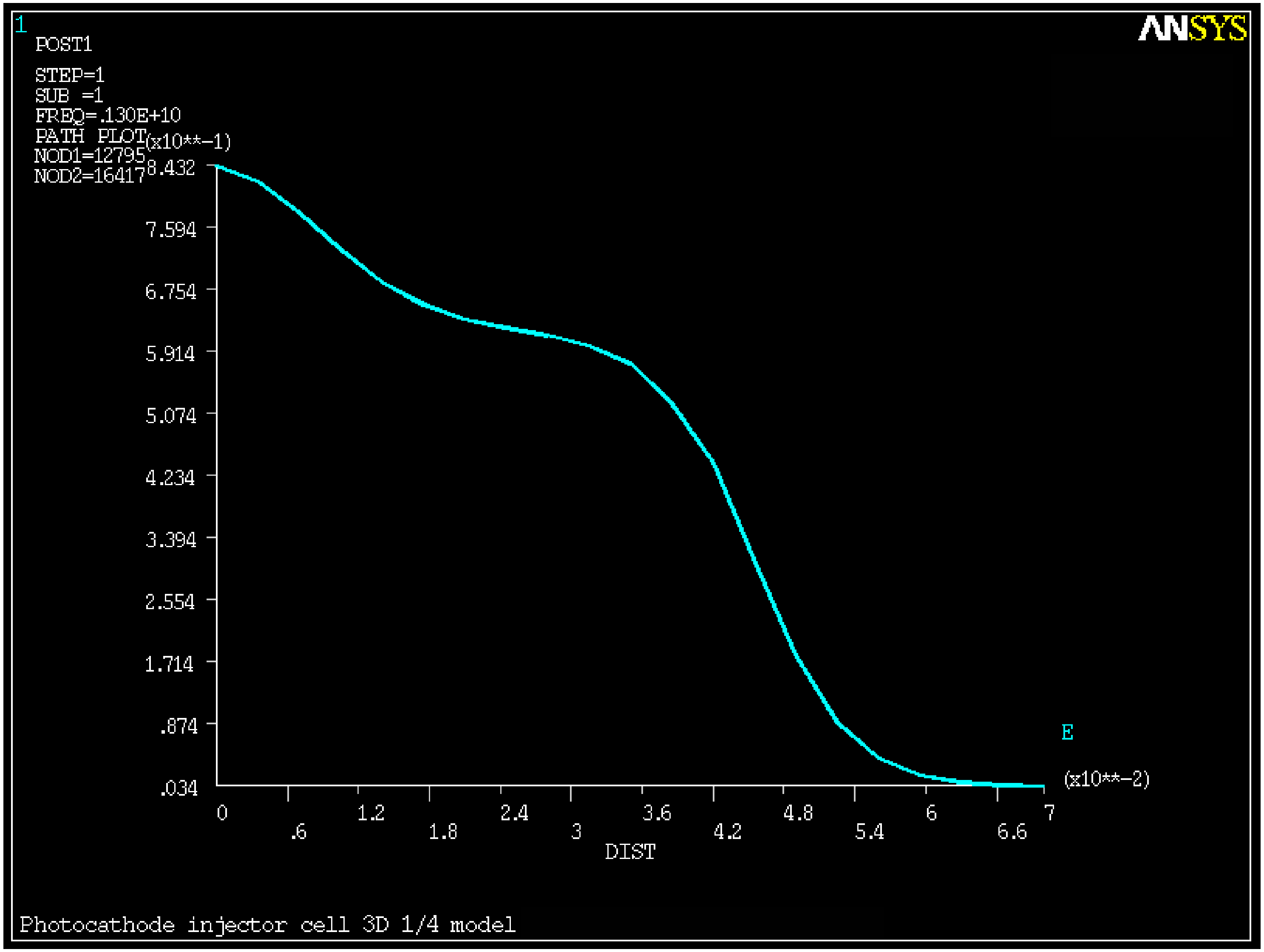
Analysis Methodology - RF Modeling

- Initial phase of the analysis entails performing a high frequency electromagnetic analysis of the cavity vacuum volume
- Model run time is reduced by taking advantage of cavity symmetry
- Vacuum volume is meshed with tetrahedral RF elements (HF119) with a finer mesh in areas of high fields
- Electric wall and impedance boundary conditions are applied to exterior surfaces representing the cavity wall-to-vacuum interfaces
- Model symmetry planes default to magnetic walls
- A modal RF analysis is run resulting in calculation of the cavity frequency and Q as well as normalized data for the E and H fields

Cavity RF Model Mesh



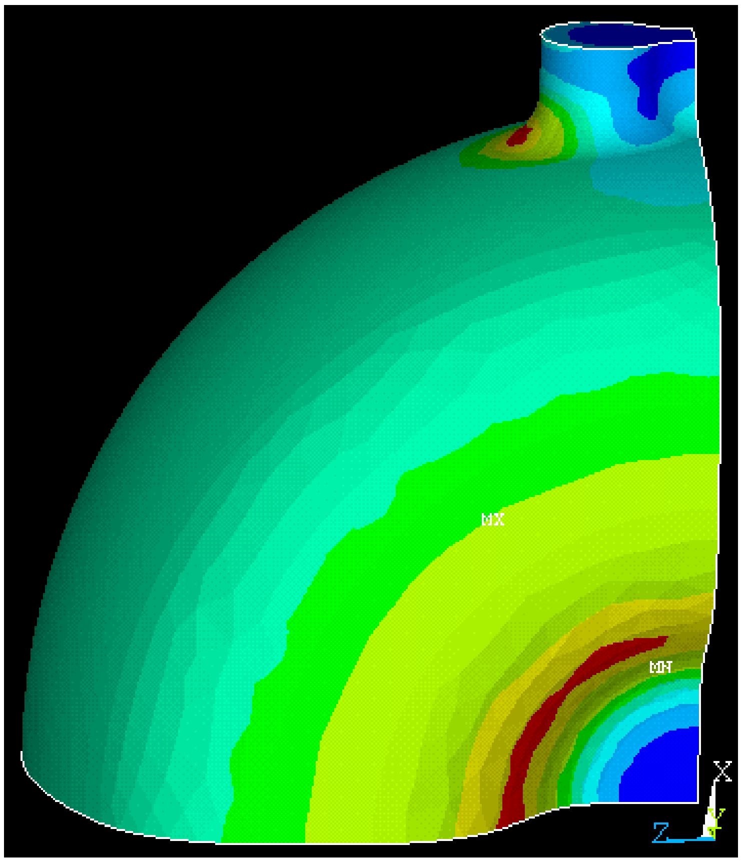
Normalized E-Field along Cavity Axis

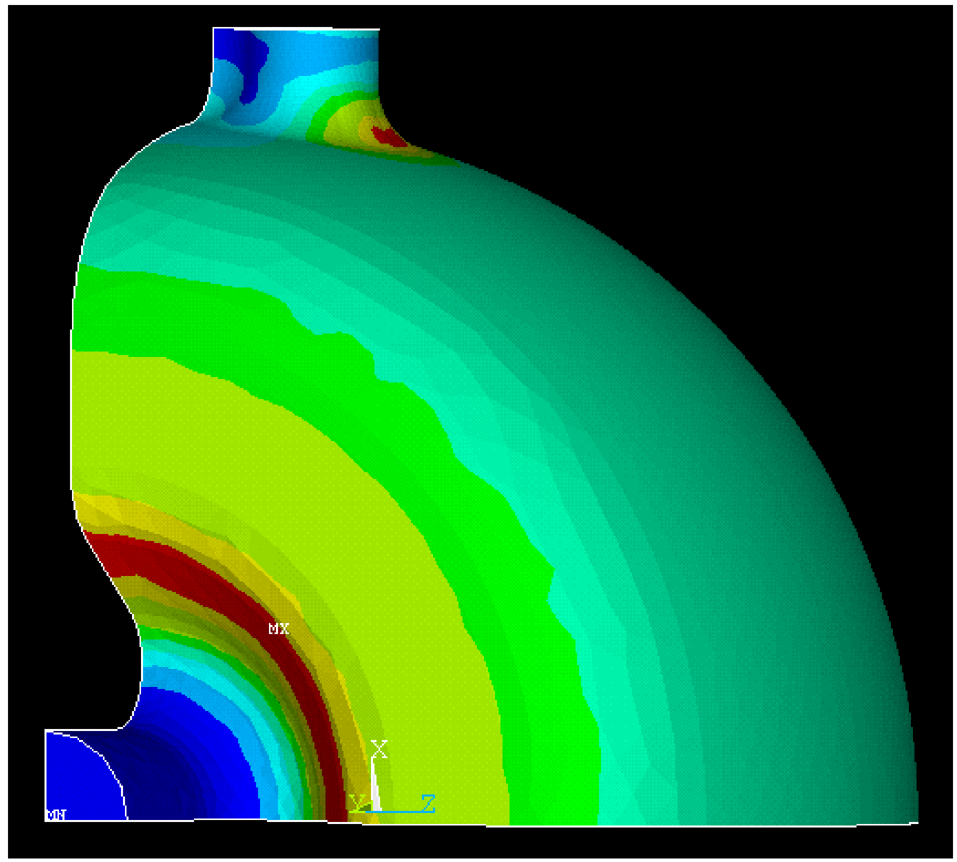


Analysis Methodology - Heat Flux

- The initial step in developing the thermal model is to generate a new mesh on the cavity surface that matches node-for-node the mesh on the surface of the RF model
- The new mesh consists of surface effect elements (SURF 152) without mid-side nodes and with heat flux loading capability
- Next, a macro consisting of an input file with a sequential list of ANSYS commands reads in the H field at each surface node
- The total cavity wall heat flux is found by summing $\frac{1}{2} \cdot R_S \cdot H^2 \cdot dA$ over all surface nodes - R_S: surface resistance, H: normalized magnetic field, dA: based on the element areas adjacent to nodes
- The results are scaled based on the known total heat loss in the cavity (31 kW in this case) and applied to the new surface elements

Calculated Wall Heat Flux

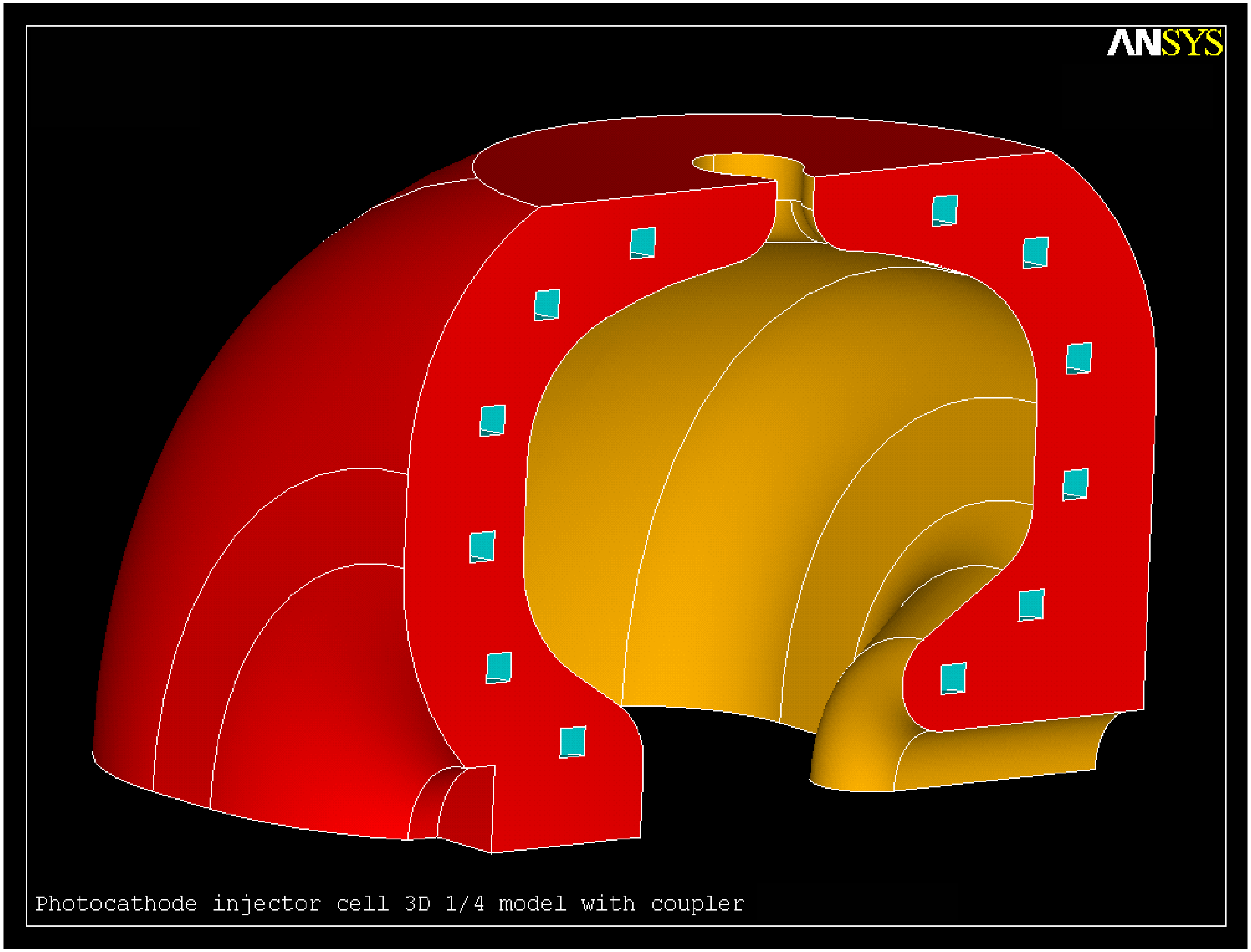




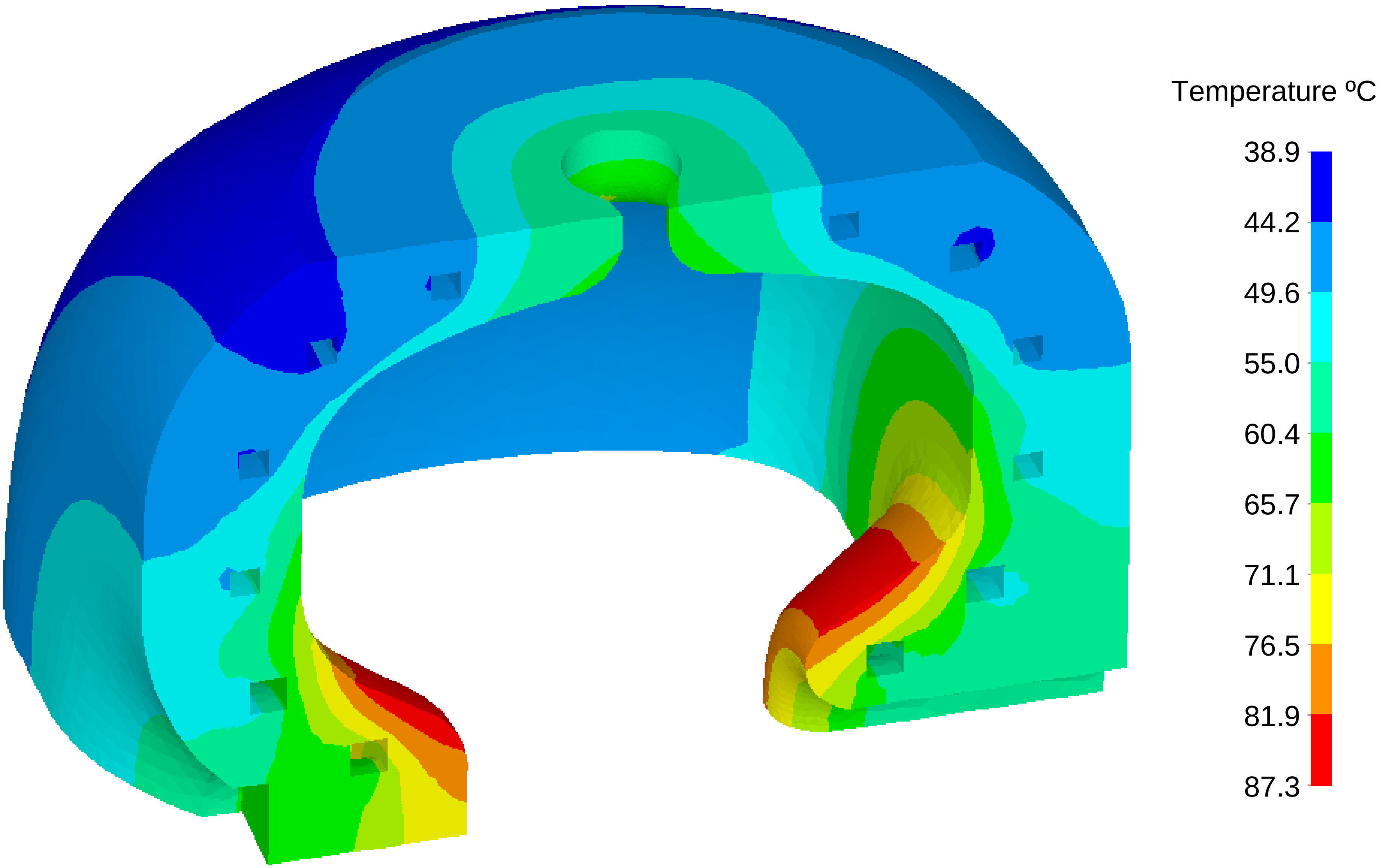
Analysis Methodology - Thermal Modeling

- Thermal analysis begins by deleting the original RF elements, leaving only the new surface elements with applied heat fluxes
- A solid model representing a conceptual design of the actual cavity walls is constructed around the existing surface elements
- The model includes relevant features: cooling passages, ports, etc.
- Upon meshing with the appropriate thermal elements, heat fluxes from the surface mesh are automatically mapped onto the model
- Heat balance is achieved by applying convective cooling to the surfaces of the water passages
- Solution of the thermal model results in nodal temperature results throughout the cavity walls (peak temperature reached is 87°C)

Cell 1 Cavity Wall 1/4 Model



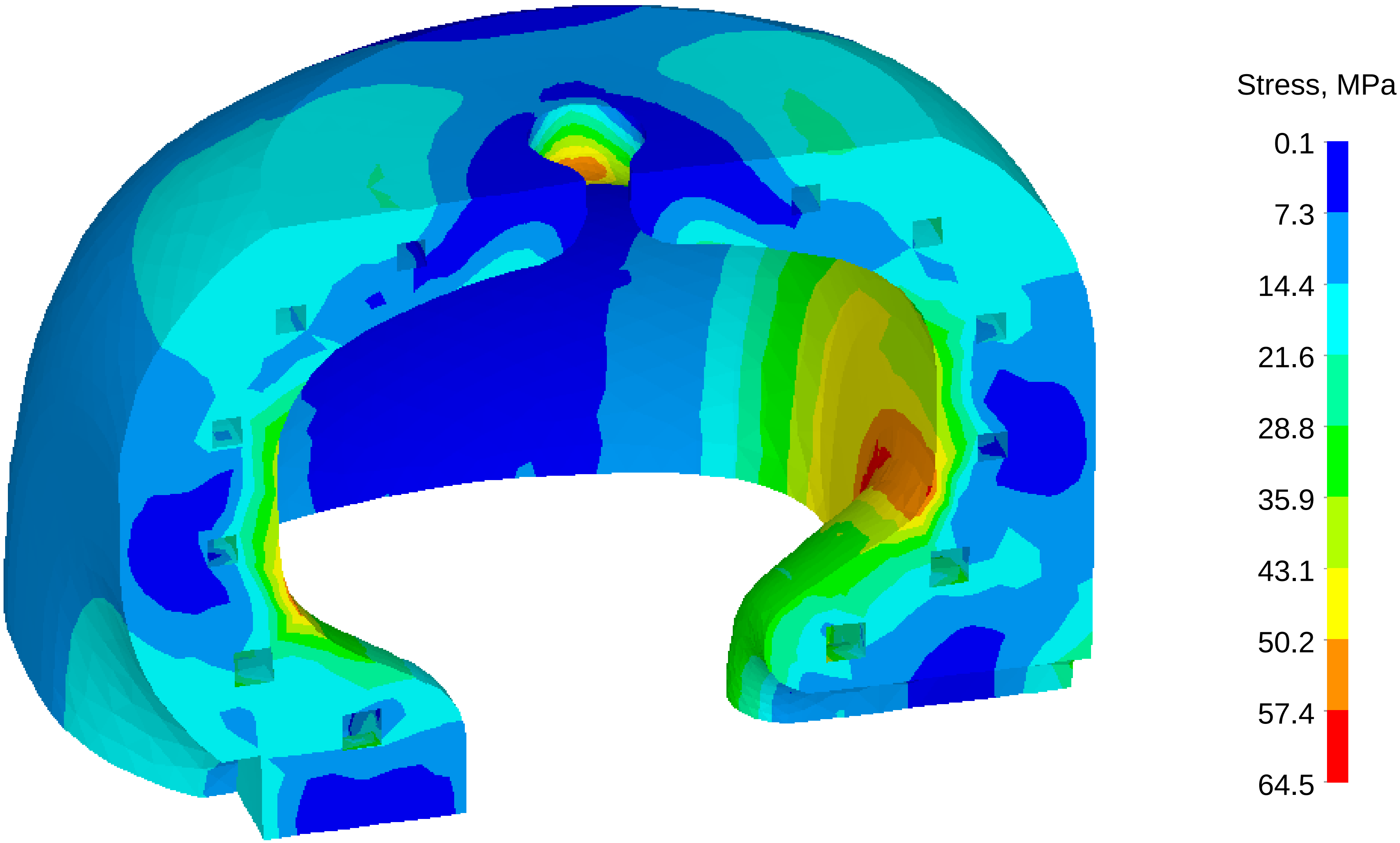
Cavity Thermal Solution



Analysis Methodology – Structural Modeling

- ANSYS allows direct solution of the structural problem by converting the thermal elements to equivalent structural elements
- The temperature data obtained from the thermal solution can be automatically applied as a load on the structural model
- Vacuum loads, symmetry boundary conditions and cavity support constraints are applied to the model as well
- The peak von Mises stress in the photoinjector was found to be approximately 65 Mpa
- Care must be taken when initially defining the mesh density of the RF model since mesh on the cavity wall surfaces will remain unchanged during RF, thermal and structural modeling

Cavity Stress Solution



Analysis Methodology - Frequency Shift

- Cavity wall displacements due to the loading conditions, including thermal distortion, are also obtained from the structural solution
- Nodal displacements at the cavity/vacuum interface, taken at the symmetry plane without the iris coupler, are added to the original nodal locations to yield a 2-D profile of the displaced cavity shape
- A new RF model based on the displaced profile is used to predict frequency shift due to various loading and thermal conditions
- To verify the procedure, the model was run again with the only change being to the cooling water temperature
- Resulting frequency shift: -23.0 kHz/°C ΔT in water temperature
- Agrees to within 0.5% of the expected sensitivity based on the product of the nominal cavity frequency and the cavity material α